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Factors Affecting Stream Transport of Combined Sewer Overflow Sediments

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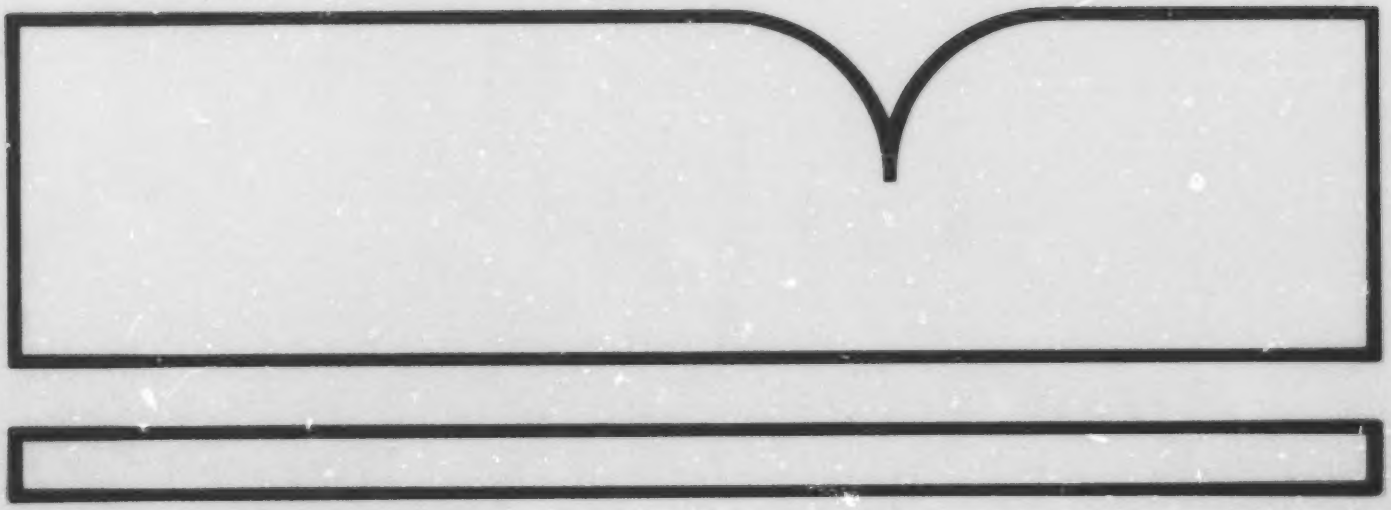

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16. ABSTRACT

Combined sewer overflow (CSO) sediments are composed of wastewater and surface runoff, typically from urbanized areas. The relative amounts of these two types of flows will depend on a variety of factors such as the intensity of rainfall and the time of day and year. Because the characteristics of wastewater and urban runoff are quite different, it should be expected that characteristics of CSO's for any particular area would fluctuate markedly. There is a significant body of data that characterizes the two types of flows individually, and from these data, it is possible to infer the composition of CSO's.

The approach taken here was to characterize wastewater and urban runoff individually and then to extrapolate these characteristics to obtain CSO characteristics of importance to the physical transport of CSO solids. Because the impact of CSO solids on water quality may be related more to the materials attached to the transported solids, an indication of the types and characteristics of these materials is also be presented. Although many reactions can occur that will not significantly affect the transport potential, such reactions must be considered for a complete water quality modeling effort.

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Factors affecting stream transport of combined sewer overflow sediments

Stanley L. Klemetson

Combined sewer overflow (CSO) sediments are composed of wastewater and surface runoff, typically from urbanized areas. The relative amounts of these two types of flows will depend on a variety of factors, such as the intensity of rainfall and the time of day and year. Because the characteristics of wastewater and urban runoff are quite different, it should be expected that characteristics of CSOs for any particular area would fluctuate markedly. There is a significant body of data that characterizes the two types of flows individually, and from these data it is possible to infer the composition of CSOs.

The approach taken here was to characterize wastewater and urban runoff individually and then to extrapolate these characteristics to obtain CSO characteristics of importance to the physical transport of CSO solids. Because the impact of CSO solids on water quality may be related more to the materials attached to the transported solids, an indication of the types and characteristics of these materials will also be presented. It should be noted that many reactions can occur that will not significantly affect the transport potential. For a complete water quality modeling effort, such reactions must be considered.

GENERAL CHARACTERISTICS

The term "characteristics" means both the physical characteristics, such as size and composition, as well as the time-varying characteristics, such as quantity and chemical properties. To successfully model the fate and effects of the sediment material from sewer and combined sewer outfalls, information on both is necessary.

A thorough search was made of current literature concerning urban runoff. All relevant information on the physical characteristics, chemical properties, and time variation of sewer-related sediment material was gathered. Those portions of this information relevant to modeling are presented below. The quality of the data varies widely, but limited generalizations were drawn wherever possible.

Wastewater flows vary with location and time. Two distinct daytime peaks typically occur, and the ratio of maximum and minimum flows over the course of a day typically ranges from three to five. Wastewater strength also varies over the course of a day. The fluctuations for many of the constituents are not as pronounced as the fluctuations in flow, and average values are useful (although site-specific data are essential to characterize individual locations). Average concentrations of selected parameters are listed in Table 1.[1]

Characteristics of urban surface runoff are more difficult to quantify than are those of wastewater. This is largely because of the difficulty of obtaining representative samples. Concentrations of the various parameters of interest in urban surface runoff also vary markedly with time, and the runoff events are often of short duration. There are two stages in gathering data on urban stormwater characteristics. The first of these is to measure the accumulation and composition of dust, dirt, and other materials on street surfaces. The second method is the end-of-pipe measurement of flow and pollutant concentration.

The street solids make up a portion of the solids in urban runoff and CSOs. Other sources are: eroded material from pervious areas, solids washed from nonstreet impervious areas, re-entrainment of previously deposited materials (dry-weather deposition) in the conveyance system, atmospheric washout, and the sanitary portion of the overflow. Furthermore, the street-sampled material (removed by sweeping, vacuuming, or flushing techniques) may not be related in the same proportions by the storm washoff process (that is, the particle distribution of street-sampled material is not necessarily equal to the distribution of street solids in the runoff). In other words, the street solids assumption[9] is not entirely accurate for urban runoff or CSOs.[2] While the end-of-pipe method is the most representative of the actual characteristics of CSOs during a given storm event, the data is difficult to obtain and is also site-specific; therefore, the street-surface data are often more useful for predictive modeling.[3] A qualitative description of a runoff event in terms of flow rate, parameter concentration in the surface runoff, and total parameter load transmitted by the runoff is given in Figure 1.[4,5]

The contribution of sanitary waste may be negligible at peak flows, but its effect on time-dependent changes in overflows may be important.

Each of the quantities plotted in Figure 1 varies with time. The hydrograph, or "flow" line, reaches a peak value at some time after the flow begins. This is related to the "time of concentration," the time required for runoff generated in the drainage areas to reach the flow measurement points. The concentrations of many parameters of interest decrease with time, a phenomenon that has been indicated by many researchers and is referred to as the "first-flush" effect. This phenomenon may become less pronounced as the size of the drainage basin and intricacy of interconnecting sewers increases.[5] The product of the flow and the concentration is the mass rate, which reaches a peak at some time after runoff occurs.

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Table 1—Reported concentrations for typical raw domestic sanitary wastewater flows.[1]

Constituent	Average concentrations, mg/L
TS	860
TSS	160
BOD_5	150
COD	320
Total N as N	30
Total P as P	8
Cl^-	50
Pb	34
Zn	7
Coliforms (MPN/100 mL)	10^6

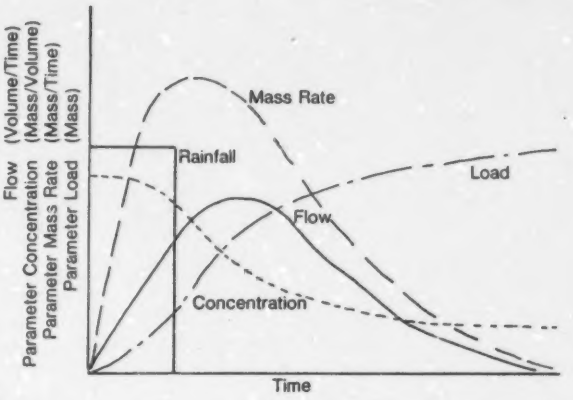

Figure 1—Qualitative description of an urban surface runoff event.[5]

Another phenomenon that has been reported and that is not indicated on the figure is variability in characteristics as a function of time of year. Kleusener and Lee[6] observed this to be particularly true in the case of certain nutrients. It may be true for other parameters. For example, suspended solids (SS) concentrations may be higher in the spring before grass is established than in the summer.

As can be seen from Figure 1, average parameter concentrations for surface runoff, as are often reported, are probably not very meaningful. However, average values are derived from analyses of samples collected during runoff events and as such may give some indication of the types and concentrations of constituents that may be found. Typical values for concentrations in urban surface runoff have been reported by Manning[1] and Pitt.[7]

Parameter concentrations are a function of, among other things, volumetric flow rate, time from beginning of the storm, time from the last storm, and time from the last peak. Colston[8] presented data that characterize a watershed in Durham, N. C. Although very site-specific, the data indicate that concentrations of various parameters are primarily functions of the time from the beginning of the storm and volumetric flow rate, with past history of the drainage areas less important. However, the volumetric flow rate is a function of the size of the catchment. Colston presented this equation

$$C = bQ^m t^n \qquad (1)$$

Where

C = Concentration, mg/L,
Q = volumetric flow rate, m^3/s (cfs),
t = time from the beginning of the storm, hours, and
b, m, n = empirical constants.

Colston's results indicate that for nearly all of the parameters studied, a peak concentration occurs during the initial "rising leg" of the hydrograph. This peak typically occurs at the beginning of the storm, although for several of the parameters studied, there is an initial increase in concentration with time followed by a decrease. Such a peak corresponds to the first-flush effect. The magnitude of the effect seems to vary among parameters. A summary of the coefficients is presented in Table 2.[8]

Work was completed recently by Huber *et al.*,[9] for the actual CSO stormwater quality data for 35 storms in eight locations. Some of the data for 5-day biochemical oxygen demand (BOD_5) and SS were statistically analyzed. This work is still preliminary, and future regression analysis of the data was conducted to help find causative relationships among the water quality parameters and hydrologic and demographic factors.

Typical data for wastewater, urban surface runoff, and CSOs are presented in Table 3.[1,10] This table gives an indication of the qualitative effects of combining wastewater with urban surface runoff. The differences noted between these values and those reported in the previous tables support the need for future work to determine which factors affect water quality.

It is readily apparent that CSO characteristics will depend on the relative volumes of urban surface runoff and wastewater.

Table 2—Empirical constants for the equation $C_{(mg/L)} = bQ^m t^n_{(hr)}$ for parameter concentration in urban surface runoff for Third Fork Catchment, Durham, N. C.[8]

Parameter	b (Q in m^3/s)	b (Q in cfs)	m	n
COD	167	113	0.11	−0.28
TOC	32	32	0.0	−0.28
TS	692	420	0.14	−0.10
TVS	179	130	0.09	−0.11
TSS	504	222	0.23	−0.16
VSS	83.6	44	0.18	−0.17
TKN	18.9	0.85	0.87	−0.29
Total P	0.89	0.80	0.03	−0.29
Al	12	10	0.05	−0.15
Ca	3.0	12.5	−0.4	−0.09
Co	0.13	0.07	0.18	+0.13
Cr	0.16	0.18	−0.04	+0.06
Cu	0.11	0.08	0.10	+0.09
Fe	10.8	4.6	0.24	−0.18
Pb	0.42	0.27	0.125	−0.29
Mg	9.31	10.0	0.02	−0.16
Mn	0.67	0.45	0.11	−0.27
Ni	0.13	0.12	0.03	−0.01
Zn	0.31	0.22	0.10	−0.22

Table 3—Typical concentrations for wastewater, urban surface runoff, and combined sewer overflows.[1,10]

Constituent	Concentration, mg/L		
	Wastewater	Urban surface runoff	Combined overflows
TS	700	496	589
TSS	200	415	370
BCD_5	200	20	115
COD	500	115	375
Total N	40	3 to 10	9 to 10
Ortho PO_4 as P	7	0.6	1.9

These, in turn, will depend on a variety of factors, including time of day, intensity of rainfall, time since the beginning of the rainstorm, and time of year, among others.

Table 3 indicates that wastewater can be expected to significantly influence the concentrations of most constituents. The important exception is SS, notable in light of the purpose of this report. Wastewater and urban surface runoff SS concentrations are roughly equivalent, so if urban surface runoff contributes the majority of the volume of a CSO, as would be typical, its SS characteristics would be similar to those of the urban surface runoff.

Transport characteristics. Because CSOs can affect the quality of receiving waters, their movements are important. The water quality effects will depend on both the location of the CSO material at any time and the characteristics of the material that affect water quality. This paper focuses on movement of CSO solids.

The contributions of solids by wastewater may be small and these solids will probably have a minor effect on the outfall characteristics of CSO solids. Little research effort, however, has been directed toward quantifying the relative significance of wastewater and urban surface runoff on CSOs.

Time-dependent changes in the physical characteristics of CSO solids may be significantly affected by wastewater. For instance, wastewater will play an important role in any nutrient

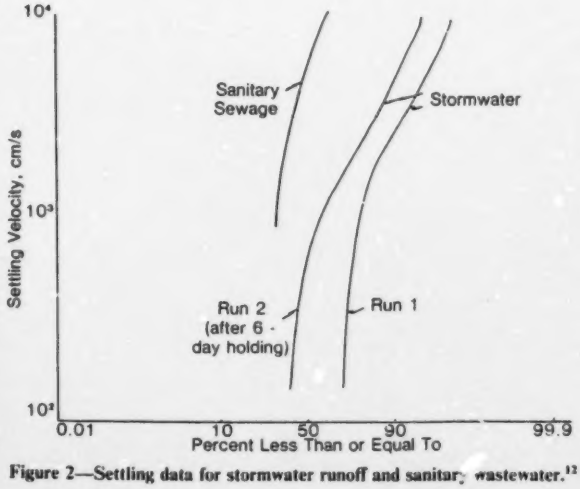

Figure 2—Settling data for stormwater runoff and sanitary wastewater.[12]

Table 4—Particle size distributions for urban street surface particulates.[13]

Size range (μm)	Percent distribution, weight
>4800	5.9
2000 to 4800	15.7
840 to 2000	14.0
246 to 840	22.2
104 to 246	17.6
43 to 104	11.0
30 to 43	7.3
14 to 30	3.8
4 to 14	2.1
<4	0.4

reactions that lead to changes in the physical characteristics of the CSO solids. The effects of these reactions might be completely different if only urban surface runoff were involved.

Combined sewer systems are generally designed to handle the peak sanitary flow plus a part of the urban runoff flow. A common basis for design is to provide for a maximum flow of two to four times the average dry-weather flow. This provides a margin of safety for the anticipated peak sanitary flow. On the average, therefore, overflow from a combined sewer will occur only when the urban runoff is from one to three times the sanitary flow. Significant overflow, on the average, will occur only for urban runoff volumes greater than these values. It is assumed for this study that CSOs consist primarily of urban surface runoff.

Urban surface runoff accounts for the bulk of the solids in CSOs. (Although concentrations are roughly equal, the volume of surface runoff is much greater.) Colston[8] found that for one urban watershed, urban surface runoff accounted for 95% of the total annual SS loading on the receiving water. Randall *et al.*[14] obtained a similar result for a larger, mainly urbanized watershed. Because such a large percentage of the SS load is contributed by urban surface runoff, the characteristics of the solids in CSOs might be expected to be similar to those of urban surface runoff alone.

In modeling the transport of CSO solids, two basic classes for processes must be considered. First, transport depends on the quiescent settling characteristics of the solids. Second, any time-dependent changes in the settling characteristics, mass rate, or other transport variables must be included in the analysis.

Table 5—Particle size distribution for street solids samples from Chicago, Ill.[1,14]

Size range (μm)	Percent distribution by weight		
	Commercial site	Industrial site	Average
2000	5.8	3.4	4.6
1190 to 2000	7.8	7.0	7.0
840 to 1190	5.2	6.4	5.8
590 to 840	6.6	12.8	9.7
840	74.6	70.4	72.5

Table 6—Particle size distribution for street solids samples from Washington, D. C.[1,15]

Size range (μm)	Percent distribution by weight				
	Arterial roadway	Urban highway	Shopping center	Commercial street	Average
1700 to 3350	3.2	8.7	1.8	5.5	4.8
850 to 1700	7.1	9.6	6.3	8.0	7.8
420 to 850	19.4	14.4	19.7	18.6	18.0
250 to 420	25.2	14.3	25.4	23.0	22.0
150 to 250	19.1	12.3	15.4	16.3	15.8
75 to 150	17.6	17.2	16.4	17.0	17.0
45 to 75	7.6	13.4	10.8	10.6	10.7
45	0.6	10.0	4.3	1.0	4.0

Reported settling data. The most direct method of quantifying the physical characteristics that relate to transport may be to measure settling velocities under quiescent conditions. Unfortunately, data of this type are limited. Dalrymple *et al.*[12] presented settling data for both stormwater runoff and wastewater, and these data are reproduced in Figure 2.[12] For the samples tested, the stormwater solids settled more slowly than the wastewater solids. No information was presented to characterize the drainage basin or indicate the condition under which the samples were collected. Therefore, the data are probably unrepresentative of CSOs in general.

One important conclusion can be drawn from the data in Figure 2. The stormwater sample was split and analyzed at two different times and an increase in the rate of settling was observed after the sample was "aged". Apparently, time-dependent processes occurred to change the physical characteristics of the sample. These types of processes will very likely be important in characterization of CSO transport.

Generated settling data. Few definitive data are available that describe the settling characteristics of CSO solids. This information is essential for development of a transport model for CSO materials. One approach could be to collect samples from each overflow of interest and characterize the material in the laboratory; this would be difficult and expensive. A second alternative would be to attempt to generate settling data from the available data. An approach to generating the required data will be presented, along with an outline of research needs to develop a procedure for estimating CSO characteristics without extensive field work for specific locations.

The variables that affect quiescent settling of discrete nonreactive particles are particle size, specific gravity and shape, and fluid density and viscosity. These types of data are available from a variety of sources, and from them it is possible to generate data that may be at least representative of expected CSO solids characteristics.

Particle size data were obtained in several studies. Solids in urban surface runoff originate mainly from impervious surfaces.[4] Because of the inherent difficulties in obtaining representative CSO samples, a number of researchers have taken street-surface sample data to be representative of CSOs.

Sartor and Boyd[13] presented data for street-surface samples from five cities. Averages of these values are presented in Table 4.[13] Similar data are presented in Table 5 for Chicago[1,14] and in Table 6 for Washington, D. C.[15]

Dalrymple *et al.*,[12] presented results from previous studies for CSO particle size distributions. These data are summarized in Tables 7[12,16] and 8.[12,17] It should be noted that the Table 7 data were for solids retained in a catch basin, from which some particles, especially those in the smaller size fractions and less dense, could be lost.

The data of Tables 4—8 are presented graphically in Figure 3. In constructing this figure, it was assumed that the geometric mean of each size range represented the midpoint of the weight of material within the range. For example, in Table 8, the size fraction of 2000 to 4800 μm contained 15.7% of the sample by weight, with 5.9% of the sample larger than 4800 μm. It was then computed that

Table 7—Particle size SS distribution in CSOs in Lancaster, Pa.[12,16]

Size range (μm)	Percent distribution by weight
9525	1.77
4760 to 9525	1.06
2000 to 4760	1.40
1190 to 2000	1.88
590 to 1190	3.10
420 to 590	2.78
210 to 420	7.01
149 to 210	5.19
74 to 149	20.10
44 to 74	23.80
44	31.90

Note—These data represent material retained in a catch basin, rather than actual CSOs.

Table 8—Particle size distribution SS in CSOs in San Francisco, Calif.[12,17]

Size range (μm)	Percent distribution by weight
3327	5.1
991 to 3327	8.8
295 to 991	15.9
74 to 295	21.8
74	48.3

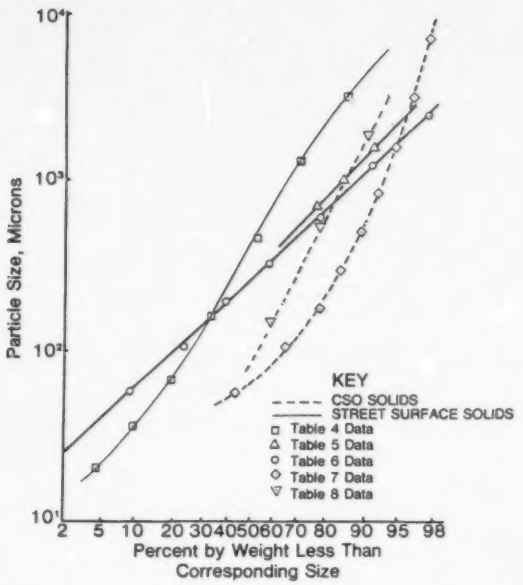

Figure 3—Particle size distributions of CSO and street surface solids.

$$100 - (15.7/2) - 5.9 = 86.2\%$$

of the sample had sizes smaller than

$$\sqrt{(2000)(4800)} = 3100\ \mu m\ (3.1\ mm)$$

Inspection of Figure 3 indicates reasonable correspondence between the size distributions of CSO solids and street-surface solids. The data of Tables 4 and 7 generally bound the distribution curves. It was noted in Table 7 that the data represent solids retained in a catch basin. It is reasonable to expect that some of the smaller particles were washed out of the basin. Removing more fines from the sample would shift the distribution curve up to the left. The size distribution of the original CSO solids would probably fall to the right of the curve shown. As an initial estimate, it is reasonable to assume that CSO solids and street-surface solids have the same characteristics, at least when the solids are first picked up by the rainfall-generated runoff.

Table 9—Fraction of constituent associated with street solids, particle size ranges.[13]

	Particle size, (μm)					
Parameter	**>2000**	**804–2000**	**246–840**	**104–246**	**43–104**	**<43**
TS	24.4	7.6	24.6	27.8	9.7	5.9
VS	11.0	17.4	12.0	16.1	17.9	25.6
BOD_5	7.4	20.1	15.7	15.2	17.3	24.3
COD	2.4	2.5	13.0	12.4	45.0	22.7
TKN	9.9	11.6	20.0	20.2	19.6	18.7
NO_3	8.6	6.5	7.9	16.7	28.4	31.9
PO_4	0	0.9	6.9	6.4	29.6	56.2
Total heavy metals	16.3	17.5	14.9	23.5	27.8*	
T Pesticides	0	16.0	26.5	25.8	31.7*	
Cr	26.1	13.6	16.3	16.3	27.7*	
Cu	22.5	20.0	16.5	19.0	22.0*	
Zn	4.9	25.9	16.0	26.6	26.6*	
Ni	26.2	14.2	15.3	17.2	27.1*	
Hg	16.4	28.8	16.4	19.2	19.2*	
Pb	1.7	2.6	8.7	42.5	44.5*	

* Particle size less than 104.

Table 10—Fraction of constituent associated with street solids, particle size ranges (Washington, D. C.).[1,15]

	Particle size (μm)				
Constituent	**3350–850**	**850–420**	**420–250**	**250–75**	**<75**
Dust and dirt	13.6	19.8	23.9	31.3	11.4
VS	17.0	14.8	13.1	33.33	21.8
BOD_5	14.7	16.7	20.2	29.4	19.0
COD	12.8	13.4	14.7	36.8	22.3
PO_4 as P	9.4	13.7	19.3	37.9	19.7
NO_3 as N	13.6	13.3	15.7	36.1	21.4
NO_2 as N	24.5	13.6	9.8	21.8	30.3
TKN	20.1	26.0	17.5	23.9	12.6
Grease	11.6	10.3	12.5	40.1	25.5
Petroleum	10.8	9.1	12.5	39.9	27.7
Asbestos	13.0	15.5	20.5	39.6	11.4
Rubber	3.0	5.4	11.3	37.8	42.5
Pb	6.5	18.3	15.5	42.8	16.9
Cr	16.8	13.2	16.6	36.8	16.6
Ni	25.9	11.8	16.2	29.4	16.7
Zn	7.2	13.9	24.9	40.4	13.6
Cn	8.1	11.7	13.8	44.2	22.2

Several researchers have presented size distributions for certain materials found in street-surface solids. Data from two of these types are presented in Tables 9[13] and 10.[1,15] The data for Table 9 were from a large number of cities, while the data for Table 10 were for several types of roadways in Washington, D. C. Selected data from these tables were plotted on probability paper in an attempt to discern trends. Several of the plots are

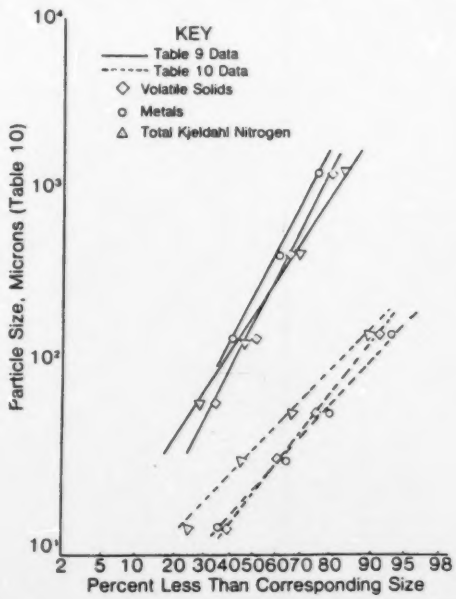

Figure 4—Size distribution of selected constituents of street surface solids.

Table 11—Typical specific gravities of material in street surface solids.[18]

Material	Specific gravity
Asphalt	1.1 to 1.5
Brick	1.4 to 2.2
Cardboard	0.69
Cement	2.7 to 3.0
Clay	1.8 to 2.6
Creosote	1.04 to 1.10
Glass	2.4 to 2.8
Paper	0.7 to 1.15
Rubber, hard	1.19
Silica	2.07 to 2.21
Tar	1.02
Wood	0.11 to 1.33
Cr	7.18 to 7.20
Cu	8.96
Fe	7.87
Hg	13.55
Mn	7.21 to 7.44
Ni	8.90
Pb	11.35
Zn	7.13

shown in Figure 4. The close agreement with linearity in all cases indicates that the constitutents shown, over the size ranges of the available data, have approximately log-normal size distributions. Other constituents from the two data sets were tested in a similar way, and in nearly all cases the agreement with linearity was good.

These observations tend to support the hypothesis that the size distribution of street solids are log-normal distributions. The mean, of course, would be a function of the geographical location. It might also be hypothesized that the size distributions are relatively independent of geographical locations and dependent on such variables as traffic volume and street-sweeping schedules. If these hypotheses could be verified, it should then be possible to generate valuable CSO transport data in terms of particle-size distributions as a function of these variables.

Particle specific gravity depends on the composition of the particle. CSO particles probably tend to change in composition, as indicated by the settling data of Dalrymple *et al.*[12] Many processes, such as agglomeration, adsorption, and biological degradation may occur. These processes are time-dependent and are functions of other variables. As a first approximation, CSO particles are assumed to be discrete and inert. This assumption is obviously not valid. The amount of error introduced cannot be determined without additional data. As a first approximation, the assumption is considered reasonable.

Specific-gravity data for materials that might be expected to be found in street-surface (and thus CSO) samples are given in Table 11.[18] To derive settling data, knowledge of the relative amounts of the various materials is necessary.

Tables 9 and 10 list some of the expected CSO materials, but do not indicate the relative amounts. Manning *et al.*,[1] compiled available data on the street-surface loadings of many of these types of materials, and some of this information is summarized in Table 12.[1,4,13–15] Data were collected for a variety of other materials, but the loadings were extremely small in most cases, and much less than those listed in all cases. What Table 12 indicates is that the bulk of street-surface solids fall into categories other than those listed. A more complete analysis of the makeup of street surface solids is necessary to apply the available density data in a reasonable way to predict settling velocities.

Table 12—Average daily accumulation on roadways in materials in the "dust and dirt" fraction.[1,4,13–15]

Material	Accumulation, kg/curb km · d
BOD	0.23
COD	2.08
Total N as N	0.02
TKN	0.03
Cr	0.01
Fe	0.95
Mn	0.02
Pb	0.09
Zn	0.02
Other*	42.00
Total dust and dirt	45.0

*Estimated by author.

In an early study, street-surface samples were collected from 20 test sites in Chicago and analyzed for seven classes of materials. A summary of the results is presented in Table 13.[1,14] In the same study, the specific gravities of street-surface samples were determined, and the results of which are given in Table 14.[1,14] The portion of the street-surface material classified in this study consists of particles larger than about 3 mm, and the "dirt" fraction was not based on composition, but was made up of the material less than about 3 mm.

Data on the composition of the small street-surface particles are incomplete. It will be assumed for the purpose of this study that the makeup of this material is the same as that given in Table 13, neglecting the "dirt" fraction. From the

Table 13—Summary of data on components of street litter in Chicago, Ill.[1,14]

Material class	Percent distribution by weight
Rock	10.3
Metal	2.4
Paper	7.6
Dirt	59.6
Vegetation	13.6
Wood	0.5
Glass	1.9
Other	4.1

Table 14—Specific gravity of "dust and dirt" street surface samples in Chicago, Ill.[1,14]

Land use	Specific gravity range
Commercial	2.2 to 3.0
Industrial	2.5 to 2.6

Table 15—Predicted data for composition and specific gravity of CSO.

Material class	Percent distribution by weight	Specific Gravity
Rock	25.5	2.6
Metal	5.9	8.0
Paper	18.8	1.1
Vegetation	33.7	1.1
Wood	1.2	0.9
Glass	4.7	2.6
Other[a]	10.2	1.2
	100.0	Weighted Average = 2.0

[a] Assumed to be rubber.

limited data available, this appears reasonable. For example, from Table 12, the accumulation of metals is 2.4% of the total, which corresponds to the value in Table 13. The actual material composition may be a function of such variables as geographical location and time of year. Development of an empirical relationship to predict the makeup of CSOs would be a valuable contribution.

If the data of Table 13 are considered generally representative of CSOs, specific gravities of the fractions can be estimated or taken directly from Table 11. Data considered representative of CSOs for the purpose of this study, in terms of composition and density, are given in Table 15. The specific gravity values are estimates and are probably variable. The weighted average specific gravity is less than the values given in Table 14, and a higher value may be more appropriate in some cases.

Particle shape is the third particle variable that must be considered in computing settling velocities. Particle shape is used in computing the drag coefficient, which is incorporated into a force balance on the particle. A relationship for the drag coefficient on spherical particles has been presented as[19]

$$C_D = \frac{-24}{N_R} + \frac{3}{\sqrt{N_R}} + 0.34 \qquad (2)$$

Where

C_D = drag coefficient,
N_R = Reynolds = $Vd\rho/\mu$,
V = Fall velocity, m/s (ft/sec),
ρ = particle density, kg/m^3 (slugs/sec),
d = particle diameter, m (ft), and
μ = fluid dynamics viscosity, P$_a$ · s (lb-sec/ft^2).

This relationship is reported to be valid to a Reynolds number of about 10^4.

A relationship that seems to fit the experimental data more closely is[20]

$$C_D = \frac{24}{N_R} + \frac{5}{\sqrt{N_R}} + 0.26 \qquad (3)$$

Experimental data are available for two other idealized shapes, disks, and cylinders. Relationships that fit these data reasonably well are

$$\text{Disks: } C_D = \frac{24}{N_R} + \frac{5}{\sqrt{N_R}} + 1.14 \qquad (4)$$

$$\text{Cylinders: } C_D = \frac{10}{(N_R)^{0.289}} + \frac{2}{\sqrt{N_R}} + 1.14 \qquad (5)$$

Some CSO particles will fall into each of these classes, but some will not be described adequately by any of the three idealized shapes. Initially, it is probably reasonable to assume that all the particles are spherical. As data are collected, this assumption may be modified as necessary.

Fluid density and fluid viscosity depend primarily on the temperature of the fluid and SS load. In most cases, it is probably sufficiently accurate to consider these variables to be functions of temperature only. A 5% error in the density value corresponds to SS load on the order of 10^5 mg/L, a solution of about 10% solids. The error in assuming the fluid transporting CSO solids to be pure water will, in most cases, be negligible.

Time can be an important factor in modeling the transport of CSO solids. The effects of time on settling characteristics may be significant.[12] Time may be important in establishing the characteristics of the street-surface solids that constitute CSO solids as indicated previously. However, initial estimates for settling characteristics of CSO solids were given in the previous section under the assumption that time-dependent changes are negligible.

Storm events that result in the urban surface runoff are time-dependent. The time of year may be important in the first part of this subsection. It also may be important in areas where the frequency and magnitude of rainfall vary seasonally. Also, the type of ground cover on pervious surfaces will influence the amount of runoff generated, as well as its size distribution. Ground cover varies throughout the year. Time of year and frequency of rainfall, as well as other time-related variables, will have an effect on the makeup and physical characteristics of CSO solids.

The concentrations of most, if not all, of the CSO constituents vary over the course of a runoff event, as demonstrated by Colston.[8] The empirical equations relating some of the constituents to the elapsed time during a runoff event are shown in Table 2. Because the concentration may vary markedly, the time-dependent nature of storm events has to be incorporated into the transport model.

Several workers have presented data for the variations of constitutent concentrations in CSOs during runoff periods. Some of the SS data are presented in Figure 5, along with three hypothetical curves obtained from Table 2. It is quite

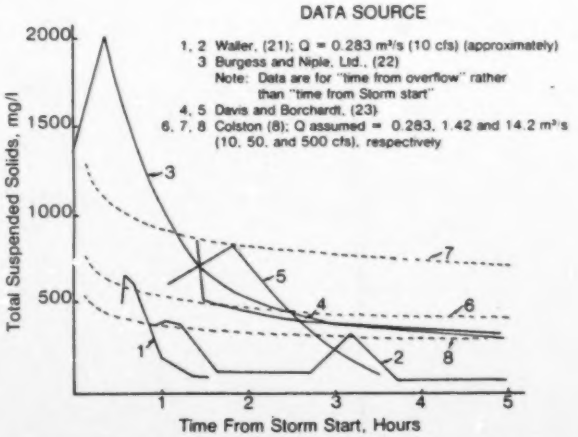
DATA SOURCE
1, 2 Waller, (21); Q = 0.283 m³/s (10 cfs) (approximately)
3 Burgess and Niple, Ltd., (22)
Note: Data are for "time from overflow" rather than "time from Storm start"
4, 5 Davis and Borchardt, (23)
6, 7, 8 Colston (8); Q assumed = 0.283, 1.42 and 14.2 m³/s (10, 50, and 500 cfs), respectively
Total Suspended Solids, mg/l
2000
1500
1000
500
1
2
3
4
5
Time From Storm Start, Hours

Figure 5—Time dependence of suspended solids concentrations in CSOs.

evident that the SS concentrations, and therefore loads, vary with time. The equation obtained by Colston does not seem to fit these data, as there is evidently a more rapid tailing off of the SS concentration in all cases than is predicted by the hypothetical equation. Developing a more reliable equation would require a significant amount of additional field data.

One equation that qualitatively fits the limited data available is

$$TSS = bQ^{0.85}t^{-1.25} \quad (6)$$

Where

TSS = total suspended solids mg/L,
Q = flow rate, m^3/s (cfs),
t = time from storm start, hours, and
b = 724 (35 for Q in cfs).

Also,

$$TSS = bQ^{1.85}t^{-1.25} \quad (7)$$

Where

TSS = total suspended solids, kg/h (lb/hr), and
b = 530 (1.6 for Q in cfs and TSS in lb/hr).

As a first estimate, lacking additional data, either these equations or the equations obtained from Table 2 may be used to estimate the time dependence of SS in CSOs. However, when the regression-analysis work on the data by Huber *et al.*[9] is completed, better data should be available for the time dependence of a variety of CSO water quality parameters.

Summary of characteristics. The contribution of wastewater to the total flow may be negligible in many cases, although its effect on time-dependent changes in the CSOs may be important. Urban surface runoff makes up the majority of CSO in most cases. The characteristics of urban-surface solids may, as a first approximation, be considered similar to those of street-surface solids.

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REFERENCES

1. Manning, M. J., *et al.*, "Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges: Volume III, Characterization of Discharges." EPA 600/2-77-064C, U. S. EPA, Washington, D. C. (1977).
2. Ammon, D., U. S. EPA, Edison, N. J. Personal Communication, August 21, (1979).
3. Berwick, R., *et al.*, "Select Topics in Stormwater Management Planning for New Residential Developments." EPA-Draft Rep., R-805238, U. S. EPA (1980).
4. Amy, F. F., *et al.*, "Water Quality Management Planning for Urban Runoff." EPA 440/9-75-004, U. S. EPA (1974).
5. Wanielista, M. P., "Stormwater Management: Quantity and Quality." Ann Arbor Science, Mich. (1978).
6. Kluesener, J. W., and Lee, G. F., "Nutrient loading from a separate storm sewer in Madison, Wisconsin." *J. Water Pollut. Control Fed.*, **46**, 920 (1974).
7. Pitt, R., and Field, R., "Water Quality Effect from Urban Runoff." *J. Am. Water Works Assoc.*, **69**, 432 (1977).
8. Colston, N. V., Jr., "Characterization and Treatment of Urban Land Runoff." EPA-670/2-74-096, U. S. EPA (1974).
9. Huber, W. C., *et al.*, "Urban Rainfall-Runoff-Quality Data Base: Update with Statistical Analysis." EPA Draft Rep., 68-03-0496, U. S. EPA (1980).
10. Metcalf and Eddy, Inc., "Wastewater Engineering." McGraw-Hill Pub. Co., New York, N. Y. (1972).
11. Randall, C. W., *et al.*, "Runoff Sediment Loads from Urban Areas." *Proc. Int. Symp. Urban Hydrol., Hydraulics, and Sediment Control*, Univ. of Kentucky (1977).
12. Dalrymple, R. J., *et al.*, "Physical and Settling Characteristics of Particulates in Storm and Sanitary Wastewaters." EPA 670/2-75-011, U. S. EPA (1975).
13. Sartor, J. B., and Boyd, G. B., "Water Pollution Aspects of Street Surface Contaminants." EPA-R2-72-081, U. S. EPA (1972).
14. American Public Works Association, "Water Pollution Aspects of Urban Runoff." EPA 11030 DNS01/69, U. S. EPA (1969).
15. Shaheen, D. G., "Contributions of Urban Roadway Usage to Water Pollution." EPA-600/2-75-004, U. S. EPA (1975).
16. Krantz, J., and Russell, D. L., "Lancaster Silo Project: Particle Sizing and Density Study." Meridian Eng., Philadelphia, Pa. (1973).
17. Envirogenics Co., "In-Sewer Fixed Screening of Combined Sewer Overflows." EPA 11-24, FKJ 10/70, U. S. EPA (1970).
18. Chemical Rubber Co., "Handbook of Chemistry and Physics." 55th Ed., *CRC Press*, Cleveland, Ohio (1974).
19. Fair, C. M., *et al.*, "Water and Wastewater Engineering." Vol. II. John Wiley and Sons, New York, N. Y. (1966).
20. Rich, L. G., "Unit Operations of Sanitary Engineering." Rich Publishing, Clemson, S. C. (1974).

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